

Radioquiet isolated neutron stars: old and young, nearby and far away, dim and very dim

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ABSTRACT. We briefly discuss the evolutionary path and observational appearance of isolated neutron stars (INSs) focusing on radioquiet objects. There are many reasons to believe that these sources are extremely elusive once the star surface has cooled down: their high spatial velocities, the long propeller stage and/or the very low accretion efficiency. We describe recent population synthesis models of close-by young INSs, highlighting the major difficulties encountered in the past by these simulations in reproducing the observed properties of known sources. As we show, a likely possibility is that most of the INSs in the Solar proximity are young (less than few Myrs) neutron stars born in the Gould Belt. To stay hot enough and sustain X-ray emission for a time ≈ 1 Myr, they probably need to be low- to medium-massive, with M less than $\sim 1.35 M_{\odot}$.

1. Introduction

Neutron stars (NSs) are among the main candidates for detection by new γ -ray missions, including AGILE (see eg Grenier, Perrot 2001 and Grenier these proceedings). Researchers usually resort to population synthesis modeling to derive estimates for the number of sources observable at present in a given energy band, and γ -rays are no exception (eg Gonthier et al. 2002 and Gonthier this volume). Up to now most such studies were based (directly or indirectly) on the assumption that radio pulsars are representative of the entire Galactic NS population. During the last decade, however, growing evidence gathered in favor of the existence of radiosilent NSs, i.e. neutron stars which are not active radio emitters. Today the possibility that a significant fraction of NSs never pass through the stage of radio pulsars is regarded as highly plausible, as already stressed several years ago by Caraveo et al. (1996). This implies that a complete picture of NSs evolution can be obtained only by taking into account also radioquiet objects. The existence of a NS population with properties quite distinct from those of ordinary radio pulsars is of importance in connection with γ -ray sources studies, since radioquiet NSs can be bright at high energies, or can have evolutionary links with other γ -ray sources (like AXPs or SGRs).

In the following we will address two main issues, the first concerning the paucity of detected X-ray emission from INSs, the second regarding the nature of a particular subclass of close-by INSs. The best known types of INSs like radio pulsars and active magnetars (AXPs and SGRs) are left out of the present discussion. In particular we will try to answer the two questions:

- why are INSs during all their evolution so dim? Especially, why there are yet no discovered old INSs powered by the accretion of the interstellar gas?
- What is the origin of the “Magnificent seven”, seven dim X-ray sources which are associated with close-by INSs?

It is useful to recall at this point the four basic stages which characterize the interaction of an INSs with the ambient medium. They play a crucial role in fixing the observational properties of INSs and are discussed in some more detail below: *ejector*,

georotator, *propeller* and *accretor* (see Lipunov 1992). In addition, as it is usually done, we term *coolers* those young NSs for which the surface temperature is high enough ($T \approx 10^5 - 10^7$ K) to make the star shine in the (soft) X-rays. We stress that while the four stages mentioned above mutually exclude each other, this is not necessarily true for the *cooler* phase. A cooler, for example, may be at the same time an *ejector*.

During the *ejector* stage the strong outflowing momentum flux produced by the spinning magnetized NS prevents the surrounding material to cross the light cylinder radius, $R_l = c/\omega$. The torque exerted by the incoming matter makes the NS to spin down. Usually, it is assumed that the magneto-dipole formula describes the rate of period increase

$$P \sim P_0 + 3 \times 10^{-4} \mu_{30} t_{\text{yrs}}^{1/2} \text{ s}; \quad (1)$$

here $\mu = \mu_{30} \times 10^{30}$ G cm³ is the magnetic moment of the NS and P_0 the initial period. The end of this stage occurs when the period reaches a critical value

$$P_E \sim 10 n^{-1/4} \mu_{30}^{1/2} v_6^{1/2} \text{ s} \quad (2)$$

where $v = v_6 \times 10^6$ cm s⁻¹ is the NS velocity and n the interstellar medium (ISM) number density. The critical period corresponds to the gravitational capture radius R_G being equal to the stopping radius R_{Sh} , where

$$\begin{aligned} R_G &= (2GM)/v^2 \\ R_{Sh} &= \left[\frac{2\mu^2 (GM)^2 \omega^4}{\dot{M} v^5 c^4} \right]^{1/2}. \end{aligned} \quad (3)$$

In the previous expressions M is the star mass and \dot{M} is the accretion rate. The stopping radius is determined by the equality of the ram pressure of the surrounding plasma ($\sim \rho v^2/2$) to the internal pressure of the relativistic wind [$\sim (\mu^2 \omega^4)/(4\pi r^2 c^4)$]. This expression is valid for $R_l < R_G$, which is true for all INSs which can leave the *ejector* stage (see details in Lipunov 1992). In deriving the second of eqs. (3) we assumed that the accretion rate is given by the Bondi formula

$$\dot{M} = \frac{2\pi(GM)^2 m_p n}{v^3} \sim 10^{11} \frac{n}{v_6^3} \text{ gs}^{-1}. \quad (4)$$

We would like to stress that the physics governing both the spin-down rate and the critical period is not yet completely understood, and this has substantial influence on the outcome of population synthesis calculations.

As we mentioned earlier, *coolers* do not represent a separate evolutionary stage, although they have quite distinct observational properties. Normally they are *ejectors* still hot enough to be visible in soft X-rays as dim sources. Young (< 1 Myr) NSs can have surface temperatures $T \approx 10^5 - 10^6$ K and luminosities $L \approx 10^{30} - 10^{32}$ erg s⁻¹ (for a review see Yakovlev et al. 1999). Such sources can be observed if they are relatively close (< 1 kpc) or if they are located in particular sites, typically young supernova remnants (SNRs), which can be targeted with deep pointings.

When the *propeller* stage is reached matter can penetrate inside the light cylinder, but the fast rotating magnetosphere does not allow fall-down onto the NS surface and the infalling gas is centrifugally driven away from the star. As the NS spins down the centrifugal barrier disappears when the period becomes less than

$$P_A \sim 300 \mu_{30}^{6/7} v_6^{9/7} n^{-3/7} \text{ s}. \quad (5)$$

After P_A is crossed, the material can reach the star surface and the NS finally becomes an *accretor*. The release of potential energy heats the gas and produces mainly X-rays.

(However, matter can accumulate around the magnetosphere if the plasma cooling rate is slow in comparison with heating. This intermediate stage is called *subsonic propeller* (Davies, Pringle 1981).)

The *georotator* stage in some sense is similar to the *accretor* one, although the NS spatial velocity is so high that matter is not gravitationally bound at the magnetospheric boundary. This happens whenever the star velocity exceeds the critical value

$$v_{geo} \approx 470 \mu_{30}^{-1/5} n^{1/10} \text{ km s}^{-1}. \quad (6)$$

2. Detectability of INSs in different stages

2.1. Coolers

According to recent theoretical investigations of NS thermal evolution, young INSs are expected to stay hot for a relatively long time (≈ 1 Myr) if they are low-mass ($M < 1.4M_{\odot}$). More massive NS cool faster. We used cooling curves by Yakovlev et al. (1999; see fig. 1) to perform a population synthesis calculation and derive the Log N – Log S distribution of close-by *coolers*. The results were then compared with observations. An important new twist of our model is the inclusion of INSs born in the Gould Belt in addition to those originating in the Galactic disk. The Gould Belt (see eg Grenier, Perrot 2001) is a collection of stellar associations rich in young, massive stars. The Sun itself is embedded in the Belt which extends in a disk-like structure for ~ 1 kpc, centered at about 100 pc from the Sun. Due to the presence of the Belt, the rate of SNs in the Solar vicinity (a region a few hundred parsecs wide) during the past $\sim 10^7$ yrs has been higher than in an average location in the Galactic disk at the same distance from the Galactic center. Since cooling curves are strongly mass-dependent (see again fig. 1), different mass spectra for NSs has been tested. The number of NSs was evaluated from available observations of SN progenitors in the solar proximity and accounting for recent calculations of SN rates.

The main results of our calculations are summarized in fig. 2. As it can be seen comparing the two theoretical curves, the contribution of NSs born in the Gould Belt is essential in reproducing the observed Log N – Log S of INSs.

The sample of thermally emitting INSs our model was confronted with (see table 1) comprises both active pulsars and radioquiet NSs. In particular it contains the seven soft, thermal X-ray radiosilent sources discovered in ROSAT pointings and known as ROSAT INSs or the “Magnificent Seven”. These sources have remarkably similar properties that make them peculiar with respect to other X-ray bright INSs, like PSRs. What is special about the “Magnificent seven”? The most likely explanation for these objects is that they are young cooling INSs, as supported by our population synthesis model (Popov et al. 2000b, 2003). For some reason all of them are radioquiet, meaning that no radio emission has yet been detected, although the possibility that the radio beams miss the Earth can not be excluded. Four objects have a measured spin period in the 10-20 s range quite larger than that of PSRs (see table 1). Moreover, none of them exhibits the hard (non-thermal) tail which is typically seen in other INSs. Does this mean that the seven represent a distinct subpopulation of NSs?

At present no definite answer can be given to this question. We just note that the seven ROSAT INSs are likely to be relatively low-massive for their temperature to be $\approx 10^6$ K after a relatively long time (≈ 1 Myr, their putative age). According to the cooling model we used this implies $M < 1.35 M_{\odot}$, so “The Magnificent seven” should be representative of the lighter part of the NS mass spectrum. We stress that while mass variations in the range 1-2 M_{\odot} have little influence on other NS parameters (eg spin, accretion rate) they are very important for the cooling history and the internal structure. Correlations between the star mass and the initial magnetic field and/or spin period may arise soon after the proto neutron star has formed, eg in the fallback process.

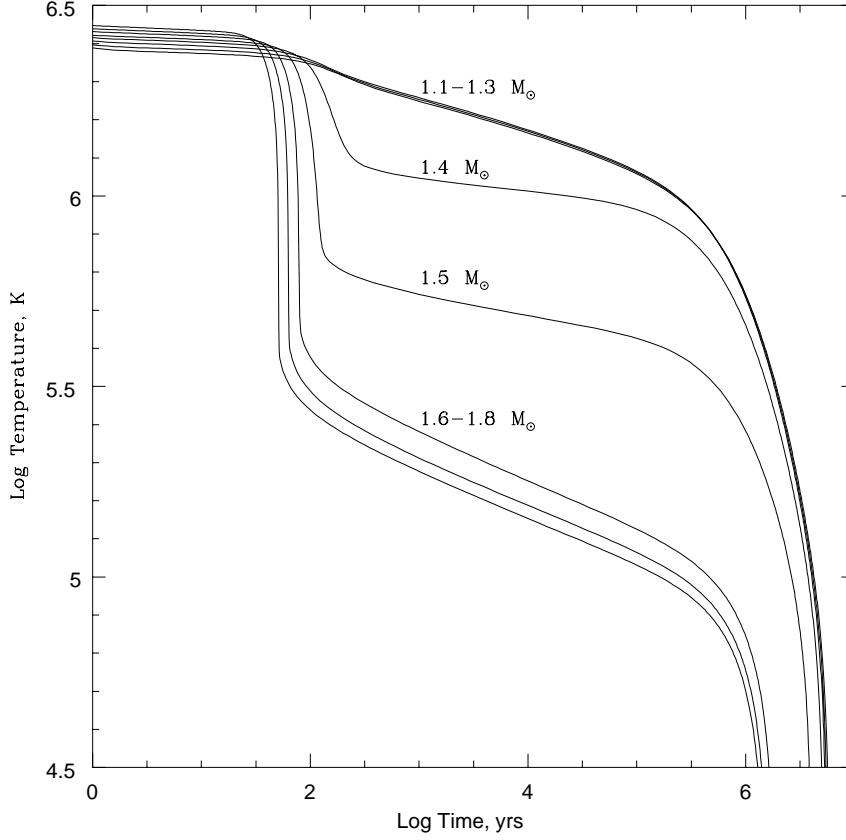


Fig. 1. Cooling history of NSs of different masses. The redshifted (i.e. observed at infinity) temperature is shown (for a detailed discussion see Yakovlev et al. 1999; Kaminker et al. 2002)

This can translate into a correlation between the temperature (the cooling history is determined by mass) and magnetic field and spin period later in the star evolution. On the other hand, a comparable number of NSs should be born with a mass above or below the critical value for fast cooling, $M < 1.35 M_{\odot}$, so the “Magnificent seven” are not expected to be unique objects.

To conclude this subsection: the “Magnificent seven” can be young *coolers* from the Gould Belt. We predict that not more than several tens of young INSs in future can be identified in ROSAT data at low galactic latitudes and some of them can also be among EGRET unidentified sources. There is a possibility, that due to processes accompanying NS birth there is a correlation between mass of compact object and its initial magnetic and spin period.

2.2. Ejectors and Georotators

According to the simulations by Popov et al (2000a) the large majority of INSs (about 90 %) never leave the *ejectors* stage if the star magnetic field is $\sim 10^{12}$ G (or lower) and does not decay. Those calculations referred to a NS population with average velocity $\sim 200 - 300 \text{ km s}^{-1}$; since P_E scales as $v^{1/2}$ (see eq. [4]), for higher mean velocities

TABLE I
Local ($D < 1$ kpc) population of young (age < 4.25 Myrs) isolated neutron stars

Source name	Period s	CR ^a cts/s	\dot{P} 10^{-15} s/s	D kpc	Age ^b Myrs	Refs
RINs						
RX J1856.5-3754	—	3.64	—	0.117 ^e	~ 0.5	[1,2]
RX J0720.4-3125	8.37	1.69	$\sim 30 - 60$	—	—	[1,3]
RX J1308.6+2127	10.3	0.29	—	—	—	[1,4]
RX J1605.3+3249	—	0.88	—	—	—	[1]
RX J0806.4-4123	11.37	0.38	—	—	—	[1,5]
RX J0420.0-5022	22.7	0.11	—	—	—	[1]
RX J2143.7+0654	—	0.18	—	—	—	[6]
Geminga type						
PSR B0633+17	0.237	0.54 ^d	10.97	0.16 ^e	0.34	[7]
3EG J1835+5918	—	0.015	—	—	—	[8]
Thermally emitting PSRs						
PSR B0833-45	0.089	3.4 ^d	124.88	0.294 ^e	0.01	[7,9,10]
PSR B0656+14	0.385	1.92 ^d	55.01	0.762 ^f	0.11	[7,10]
PSR B1055-52	0.197	0.35 ^d	5.83	~ 1 ^c	0.54	[7,10]
PSR B1929+10	0.227	0.012 ^d	1.16	0.33 ^e	3.1	[7,10]
Other PSRs						
PSR J0056+4756	0.472	—	3.57	0.998 ^f	2.1	[10]
PSR J0454+5543	0.341	—	2.37	0.793 ^f	2.3	[10]
PSR J1918+1541	0.371	—	2.54	0.684 ^f	2.3	[10]
PSR J2048-1616	1.962	—	10.96	0.639 ^f	2.8	[10]
PSR J1848-1952	4.308	—	23.31	0.956 ^f	2.9	[10]
PSR J0837+0610	1.274	—	6.8	0.722 ^f	3.0	[10]
PSR J1908+0734	0.212	—	0.82	0.584 ^f	4.1	[10]

^a) ROSAT PSPC count rate

^b) Ages for pulsars are estimated as $P/(2\dot{P})$,
for RX J1856 the estimate of its age comes from kinematical considerations.

^c) Distance to PSR B1055-52 is uncertain (~ 0.9 -1.5 kpc)

^d) Total count rate (blackbody + non-thermal)

^e) Distances determined through parallactic measurements

^f) Distances determined with dispersion measure

[1] Treves et al. (2000) ; [2] Kaplan et al. (2002); [3] Zane et al. (2002);

[4] Hambaryan et al. (2001); [5] Haberl, Zavlin (2002); [6] Zampieri et al. (2001);

[7] Becker, Trümper (1997); [8] Mirabal, Halpern (2001); [9] Pavlov et al. 2001;

[10] ATNF Pulsar Catalogue (see Hobbs et al. 2003)

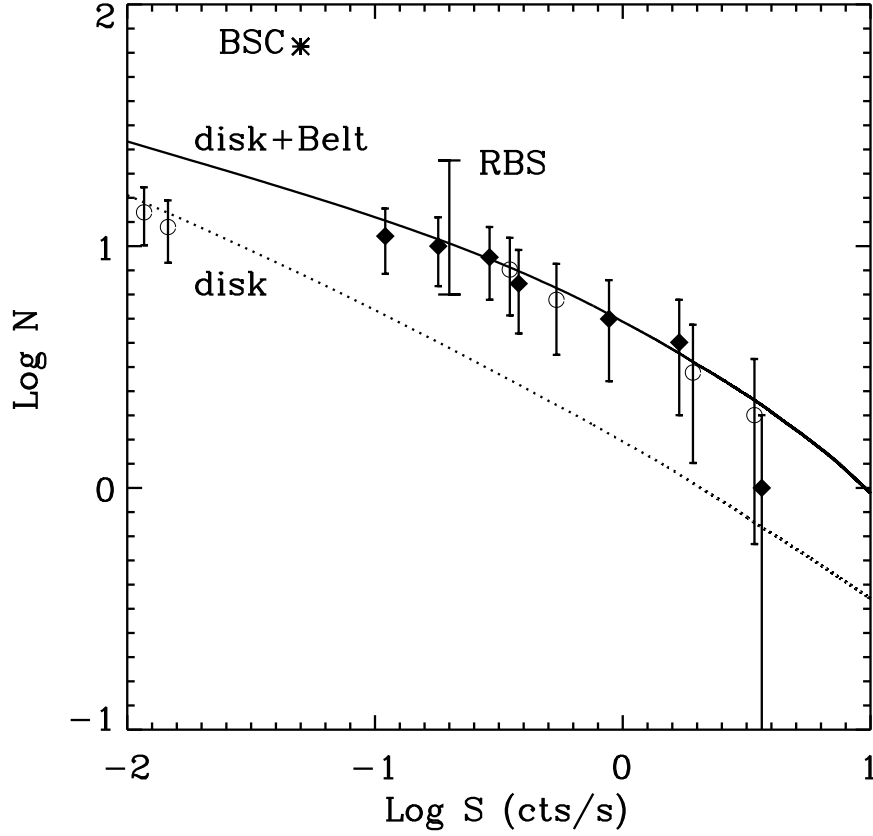


Fig. 2. Log N – Log S distribution for *coolers* (from Popov et al. 2003b). Filled diamonds are used whenever the dimmest source at a given flux is one of the seven RINSs. An open circle is used for all the other cases. The two curves give the results of our calculation: a) only stars from the Galactic disk contribute to the Log N – Log S distribution (dotted line), and b) also the contribution of the Gould Belt is accounted for (solid line). The labels RBS and BSC mark two observational limits, obtained from ROSAT data (RBS: Schwöpe et al. 1999; BSC: Rutledge et al. 2003).

the fraction of *ejectors* is even higher. We draw the reader's attention to the fact that the number of observable accreting INS is very low for high star velocities not because the accretion rate (and hence the luminosity) is low, but simply because INSs cannot reach the stage of accretion. There has been some confusion in literature about this point. Many investigators attributed the lack of observed *accretors* in ROSAT data, in contradiction with the initial predictions by Treves, Colpi (1991) and others, to the low accretion luminosity of fast-moving NSs. This would imply that the Galaxy is filled with very dim *accretors*, which is not the case! Even leaving aside further effects that can influence the duration and/or the efficiency of accretion (eg a long *subsonic propeller* stage, a below-Bondi rate; see discussion in section 2.4) the number of *accretors* (of all luminosities!) goes below a few percent if the average velocity is higher than $\approx 200 \text{ km s}^{-1}$. In this case, the number of accreting INSs is about two orders of magnitude

below the original prediction by Treves, Colpi (1991).

Let us very briefly touch some difficulties in describing *ejectors* in population synthesis models. Most population synthesis studies of INSs are based on some simple model assumptions which can be a significant oversimplification. For example, transition from *ejector* stage to *propeller* or *georotator* stage is assumed to appear when surrounding plasma can penetrate inside the light cylinder (see Lipunov 1992). However the reality can be more complicated (see for example discussion in Michel 2003), and not R_l can be the most important scale. Also we actually do not understand well enough the mechanism of energy losses on the *ejector* stage, we do not know how the braking index n evolves, we do not know if magnetic and spin axis align or contr-align (see for example Beskin et al. 1993 and Regimbau, de Freitas Pacheco 2001), we do not know if the magnetic field significantly decay during the *ejector* stage and how it is connected with spin evolution (see Konenkov, Geppert 2001). To summarize: we do not know how do *ejectors* live and die... So, the building of the population synthesis of INSs, which starts with the *ejector* stage, has not very solid basis!

We stress once more that the *ejector* phase does not necessarily coincide with a NS being an active radio pulsar. *Ejectors* comprise, in fact, also a) pulsars that already crossed the death valley and, b), NSs which never become radio loud. This means that the vast majority of Galactic NSs is at present inaccessible to observations. There has been several proposals aiming at the detection of these high-velocity INSs. Rutledge (2001) developed the idea by Harding, Leventhal (1992) that INSs in the *georotator* stage during which full-fledged accretion can not occur because the magnetospheric radius is larger than the gravitational capture radius) can still accrete warm matter from the ISM. However, the scenario proposed by Rutledge requires ultra-high ($> 10^{15}$ G) magnetic fields during the entire lifetime of a NS which sounds a rather doubtful assumption. Field decay will make this stage (called MAGAC – magnetically accreting) very short. Toropina et al. (2001) and Romanova et al. (2001) proposed that activity in a long magnetospheric “tail” can lead to observable consequences due to reconnection of the magnetic field lines, as observed in numerical experiments.

We note that the astrophysics of high-velocity magnetized INSs is far from being completely understood. Up to very recent times, the detection of such dim, high-energy sources was simply beyond imagination. The role of the star velocity in shaping the magnetosphere is definitely a very important issue in establishing their observational properties. “Mixed” stages, in which the relevant lengthscales (eg the Alfvén radius) upstream and downstream are different because of the highly non-symmetric interaction with the ISM, as discussed in Toropina et al. (2001) and Romanova et al. (2001) deserves a more thorough investigation.

2.3. Propellers

As discussed in the previous section, the number of *propellers* is very low just because virtually all NSs are *ejectors* for a non-decaying magnetic field. If the field decays, however, the situation can be the opposite (eg Colpi et al. 1998; Livio et al. 1998; Popov et al. 2000a; Popov, Prokhorov 2000). INSs can enter the region of the parameter space where the magnetic field is low enough to make the spin evolution very slow, and, at the same time, the period is not too long to allow accretion. For example, if field decay freezes at about $10^8 - 10^{10}$ G, and the decay time-scale is $\sim 10^8$ yrs, a NS with initial field $\sim 10^{12}$ G never reaches a stage where $R_A = R_{co}$ (see Popov, Prokhorov 2000).

The star enters the *propeller* stage with $P = P_E$ and starts to spin down intensively. In a relatively short time ($\approx 10^6$ yrs for $B \sim 10^{12}$ G) the spin period increases up to $P = P_A$. At that moment $R_A = R_{co}$ and if matter can penetrate the magnetosphere, it can fall down onto the star surface. However, even if $R_A < R_{co}$ a NS can avoid the accretion stage if cooling in the atmosphere above R_A is not effective. Under such

conditions, in fact, no instabilities can set in the hot plasma preventing matter to enter the magnetosphere (Davies, Pringle 1981). It is the so called *subsonic propeller* stage. Recently Ikhsanov (2003) re-investigated this issue in connection with INSs. His main conclusion is that in a realistic situation an INS spends a significant part of its life ($> 10^9$ yrs) in this stage during which only a small amount of matter can diffuse inwards and reach the star surface. If this situation is realized in nature than even low-velocity INSs may never become bright *accretors*.

One can try to investigate the existence of *subsonic propeller* using X-ray binaries (probably, Be/X-ray systems are the closest analogue to accreting INSs). However, in X-ray binaries the plasma density is higher than in INSs and results cannot be applied directly. In fig. 3 we show data for X-ray pulsars in binary systems with known spin periods and luminosities. We used also long period pulsars in Be systems, so they are expected to be far from spin equilibrium (see Lipunov 1992 for details). As it can be seen, data are in better agreement with the “normal” critical period, than with the subsonic one (the reason could be the higher plasma density in these systems). Cases when one can suspect X-ray systems to be at the *propeller* stage (filled diamonds in the figure) lie much below the others.

If the *subsonic propeller* stage is taking place then accreting INSs should have very long spin periods, probably absence of periodic pulsations can be a signature of an *accretor* (on spin period of INSs at the stage of accretion see Prokhorov et al. 2002). We note, that an INS can be an accreting object with period about 10 seconds only if its field significantly decayed (Konenkov, Popov 1997; Wang 1997). However, at least for one of the seven ROSAT INSs spin-down implying a field $B \sim 2 - 6 \times 10^{13}$ G was measured. This provides further support, in addition to the large measured spatial velocities for some of them, to reject the idea that the seven are powered by accretion (see a review of recent observational data in Haberl 2003).

2.4. Accretors

The first ideas about INSs accreting from the ISM appeared in the early 70’s (eg. Ostriker et al. 1970; Shvartsman 1971). At that time, however, it went nearly unnoticed since no detector was available to verify this idea. It was only 20 years later that, thanks to ROSAT sensitivity, that it became possible to detect such dim, soft sources. This prompted new interest and Treves and Colpi (1991) were the first to estimate the number of accreting INSs detectable with ROSAT. Their calculations predicted that a large number of accreting INSs should be visible in ROSAT exposures, basing on three main assumptions

- a large fraction of low velocity objects
- Bondi accretion rate
- most of NSs spend a large part of their lives as *accretors*.

Up to now *no* strong candidates for this class of sources have been found. The reasons for explaining the paucity of accreting INSs boils down to essentially to two: a) there are almost no *accretors*, and b) the accretion luminosity is much lower than what implied by the Bondi formula, using conventional efficiency for conversion of gravitational potential energy into radiation ($\eta \sim GM/Rc^2$). As we discussed above, there are good reasons to believe that not all INSs become *accretors*, and that even those that do so spend most of their lives in earlier stages (*ejector*, *propeller*). The NS velocity distribution alone is enough to explain the lack of bright (> 0.1 ROSAT cts s^{-1}) *accretors*. The possibility that the propeller stage is long (longer than a few Myrs as assumed, for example, in Popov et al. 2000a,b) makes the statement above even stronger.

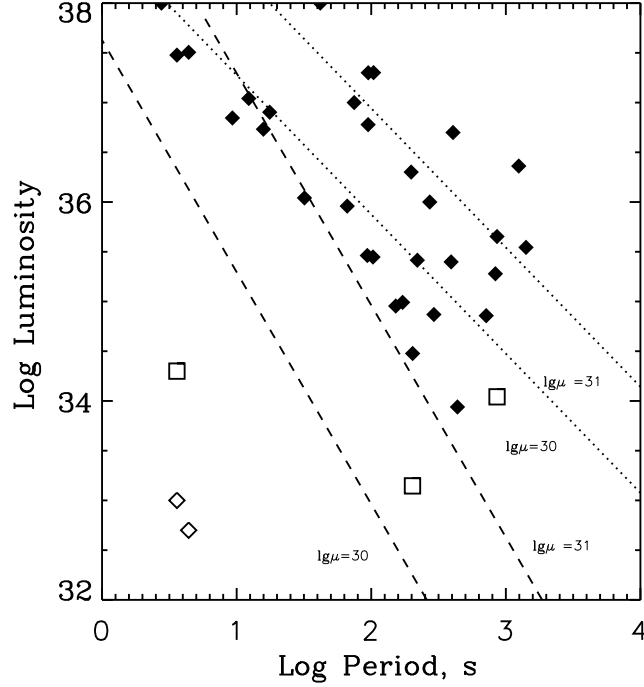


Fig. 3. Period vs. luminosity for Be/X-ray binaries; data taken mainly from Haberl, Sasaki (2000). Open symbols correspond to the quiescent state of the X-ray pulsar. Squares represent three sources in quiescence from which pulsations were observed (4U 0115+63 – Campana et al. 2001; RX J0440.9+4431 and RX J1037.5-564 – Reig, Roche 1999). Open diamonds show objects without pulsations, which are supposed to be in the *propeller* state (4U 0115+63 and V0332+53 – Campana et al. 2002). The two dashed lines correspond to the critical period, $P_A = 2^{5/14} \pi (GM)^{-5/7} (\mu^2/\dot{M})^{3/7}$, for two values of the magnetic moment, $\mu = 10^{30}$ G cm³ and 10^{31} G cm³. The two dotted lines correspond to subsonic propeller – accretor transition for the same two values of the magnetic moment which occurs at $P_{crit} = 81.5 \mu_{30}^{16/21} L_{36}^{-5/7}$ according to Ikhsanov (2003). We note that the multiplicative coefficient in Ikhsanov’s formula is larger than in the classical formula of Davies, Pringle (1981) by a factor ~ 7.5 . For most objects luminosities correspond to outburst phases, as is apparent from the plot, where the points are shifted from the equilibrium line. Equilibrium should correspond to some “average” over the orbital period luminosity.

In addition, recent investigations strongly support the idea that the Bondi rate is just an upper limit which is rarely realized in nature. There are three main reasons for which $\dot{M} \ll \dot{M}_{Bondi}$: pre-heating, magnetic effects and a low-efficiency accretion flow. As noted by Blaes et al. (1995) the UV/X-ray flux coming from the star surface will heat the incoming matter producing an increase of the gas temperature and hence of the local sound speed c_s . If the star velocity is lower than c_s the latter is governing the accretion rate and accretion is reduced. This effect is important for slow INSs and can reach 1.5 orders of magnitude for $v = 20$ km s⁻¹. Recent 2D MHD simulations have shown that accretion onto a rotating dipole is substantially different from that onto an unmagnetized star (Romanova et al. 2003; Toropina et al. 2003). Magnetic effects scales with the magnetic field strength. For lower field they are less pronounced. If the field decays

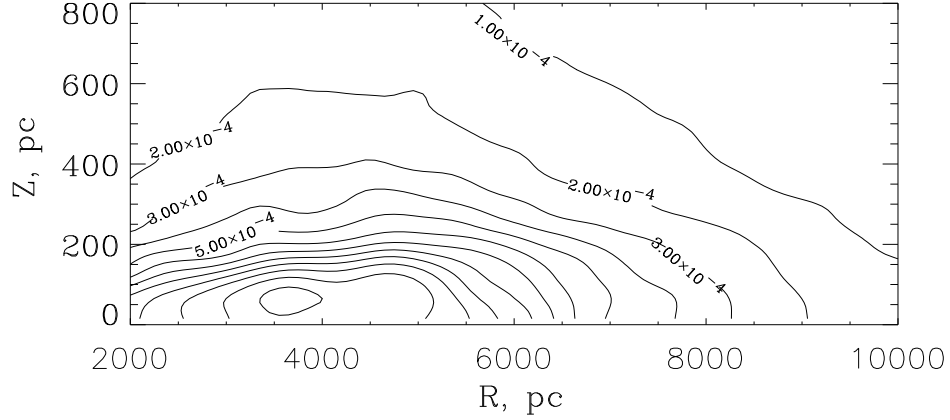


Fig. 4. Spatial distribution of INSs in the Galaxy (from Popov et al. 2003b). The data was calculated by a Monte-Carlo simulation of > 10000 individual tracks on a fine grid (10 pc in z direction and 100 pc in R direction). Kick velocity was assumed following Arzoumanian et al. (2002). NSs were born in the thin disk with semithickness 75 pc. No NS born inside $R = 2$ kpc and outside $R = 16$ kpc were taken into account. NS formation rate was assumed to be constant in time and proportional to the square of the ISM density at the birthplace. Results were normalized to have in total 5×10^8 NSs born in the described region. Density contours are shown with a step 0.0001 pc^{-3} . At the solar distance from the center close to the Galactic plane the NS density is about $2.8 \times 10^{-4} \text{ pc}^{-3}$.

significantly, these effects are not so serious, otherwise the accretion rate is reduced by more than one order of magnitude. Finally, recent 2D and 3D simulations of accretion flows show that convection can reduce the accretion rate by orders of magnitude (see Perna et al. 2003 and references therein). However, when applied to INSs the formula

$$\dot{M} \sim \left(\frac{R_{in}}{R_{out}} \right)^p \dot{M}_{Bondi}, \quad p \sim 1/2, \quad (7)$$

which is obtained in the case of black hole accretion, does not provide a strong constraint since $R_{in} \approx R_A$ and $R_{out} \approx R_G$, so, typically, $(R_A/R_G)^{1/2}$ is only about 0.1. We note also that in binaries where a NS is the accreting compact object (at accretion rates $> 10^{15} \text{ g s}^{-1}$) the Bondi formula seem to work. All the data on luminosity are in good correspondence with estimates of \dot{M}_{Bondi} , as derived from the wind parameters and geometry of these systems.

There is a hope to observe isolated *accretors* at specific sites, for example in globular clusters (GCs). It was suggested by Pfahl and Rappaport (2001) that some dim X-ray sources detected by Chandra in GCs can be old INSs accreting ISM. Simple evolutionary calculations (Popov, Prokhorov 2002) support this idea. A cluster with mass $\sim 10^5 M_\odot$ can have one accreting INS. However, this is strongly dependent on the amount and the properties of the ISM in GCs which are not well constrained at present. Additionally, young INSs can be accreting due to so called remnant (or fall-back) discs (for example Chatterjee et al. 2000, Alpar 2003). We will not discuss this possibility further here.

3. Conclusion

When Baade and Zwicky (1934) proposed the idea of neutron stars there were not many hopes to observe these objects. It was realized since the very beginning that the very small radius would make them very dim thermal emitters, unless their temperature is extremely large. It was only more than 30 years later that the existence of radio pulsars was recognized and this paved the way to the discovery of a large number of INSs. However, if an INS is radioquiet (or its radio beam misses the Earth), than the original conclusion still holds: isolated NSs are very faint objects, if they emit at all. Young INSs (ie *coolers*) are, by far, the most numerous class of known radioquiet INSs (including also the central sources in SNRs). These objects are doomed to fade in a very short time ($\approx 10^5$ yrs) if their masses are larger than some critical value which is about $1.35 M_{\odot}$. Anyway, they will cool below the detection limit in a few million years. Old INSs can be resurrected due to accretion. So the only possibility to observe an old INSs is to see it as an *accretor*. Otherwise they are extremely dim old *ejectors* with negligible spin-down losses, *propellers* or *georotators* from which there are not much hopes for any observable activity. Here we summarize the main reasons for which INSs older than $\approx 10^6 - 10^7$ yrs are expected to be substantially undetectable.

1) The high spatial velocity: a) if the magnetic field is constant with value typical of normal radio pulsars, then INSs with $v > 100 \text{ km s}^{-1}$ spend all their lives as *ejectors*; b) for a decaying field there can be realistic values of the parameters for which INSs freeze at the *propeller* stage (see section 2.3); c) for fast decay or very low initial field, when the magnetospheric barrier does not exist, accretion rate is too low for high velocity INSs to produce an observable object (see section 2.4).

2) The long propeller stage: a NS can spend nearly all its life as a *propeller* due to magnetic field decay. Also, there is the possibility that a NS can spend billions of years at the so-called *subsonic propeller* stage until it spins down to very long periods. This stage too is expected to be a very dim one.

3) The low accretion efficiency: even if a NS comes to the stage of accretion there are many reasons to expect a very low luminosity. Among these are: a) a very low accretion rate realistic average velocity of the NS population; b) preheating, which decreases the accretion rate; c) MHD effects which prevent material to reach the star surface; d) low accretion rate due to turbulence.

Anyway, at least several radioquiet INSs are already observed (the "Magnificent seven", Geminga and 3EG J1835+59, plus compact X-ray sources in SNRs and some others), and their number will grow in future also thanks to new γ -ray missions like AGILE and GLAST. As can be seen from fig. 4 there are about $(2 - 3) \times 10^{-4}$ per cubic parsec around the Sun, so there are still a lot of objects to discover.

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